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Image editing for weathering effects with geometric details

Yuki Endo · Yoshihiro Kanamori · Jun Mitani · Yukio Fukui

Abstract We present an image-editing technique that can synthesize weathering effects with fine-scale geometric variations that occur together with weathering phenomena. We extract such fine-scale geometries as high-frequency components of the image semi-automatically according to the estimated weathering distribution in the image. The geometric details are modified when (de)-weathering is applied, yielding much more realistic appearance than previous methods without adding excessive user inputs. We demonstrate the effectiveness of the present technique through comparisons with previous methods.

Keywords weathering and aging · image processing

1 Introduction

Outdoor objects in the real world change their appearance due to weathering over time. For example, metals get rust, paints peel, and stones become mossy, erode, and so on. Reproduction of such weathering phenomena is very important to enhance the reality of object appearance in computer graphics.

Several techniques have been proposed for modeling weathering effects. These techniques can be broadly grouped into sample-based approaches that handle general targets, and simulation-based methods that handle specific targets. Here we briefly introduce some of them, and refer to the survey paper by Merillou et al. [10] and the book by Dorsey et al. [7] for more information. Physically-based simulations of weathering and aging have been applied to various targets such as stones [6], paint peeling [11], rust [5] and moss [4]. These methods are meant to handle 3D models and difficult to apply to a single image. In sample-based approaches, Gu et al. [8] and Lu et al. [9] reproduce temporal variations of materials for 3D models by capturing real-world materials. However, these techniques cannot be applied to a single image because of the requirement of captures of full time sequences.

Wang et al. [13] measured BRDFs at various points on a single material that exhibits gradation of weathering degrees, and constructed an *appearance manifold* from the BRDFs, which represents the temporal variation of the material. While this method mainly targets at 3D models, Xue et al. [14] as well as Bandeira and Walter [2] proposed methods for reproducing weathering in 2D images. Both of their methods construct the models of the time-variant appearance of objects, *appearance manifolds* [14] or *appearance maps* [2], and calculate the distribution of weathering degrees in the image based on the models. The weathering degrees are then used to decompose the image into reflectance and illuminance, which is often interpreted as *shading* in this context. Consequently, (de)-weathering is accomplished by changing only the reflectance according to weathering degrees while the shading remains unchanged. This framework allows applications to objects with complicated shading, but cannot handle time-varying shading due to weathering, that is, shading caused by time-varying geometric details of rust, peeled paint or moss. Recently, Bandeira and Walter [3] tackled this problem by using normal mapping. Their approach seems to successfully reproduce the examples of cracks. However, the propagation of cracks is separately handled without using weathering degrees, and thus their method cannot handle the cases where both shading and reflectance change simultaneously according to (de)-weathering.

In this paper, we propose a technique for modeling weathering effects with time-varying geometric details in images. Specifically, we focus on spatio-temporal variations of shading as well as reflectance due to weathering. Because such variations of shading often appear in high-frequency components of the shading image, we

Y. Endo · Y. Kanamori · J. Mitani · Y. Fukui
Department of Computer Science, University of Tsukuba, Ibaraki, Japan
E-mail: endo@npal.cs.tsukuba.ac.jp

J. Mitani
JST ERATO, Tokyo, Japan

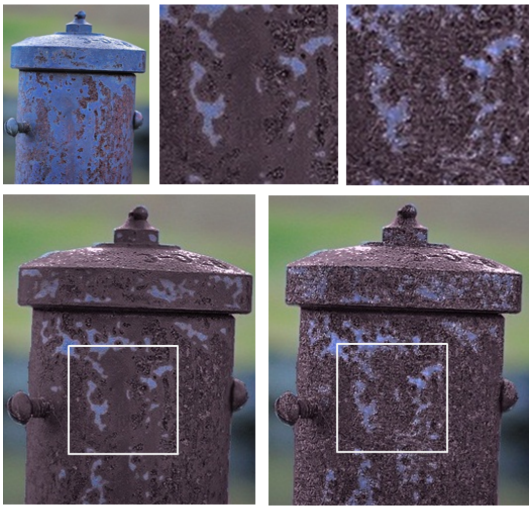

Fig. 1 Example images of rust effects. Top left: the input image. Bottom left: a resultant image by Bandeira and Walter [2]. Bottom right: a resultant image by our method, with geometric details caused by rusting. Each magnified figure is shown at the top right.

extract the high-frequency components and add them onto object surfaces when weathering progresses to a certain extent. This extraction can be done with only a few additional user inputs. (De)-weathering with time-varying shading is accomplished in our work for the first time, and substantially enhances the reality of (de)-weathering effects as shown in Fig. 1. Because our method is based on Bandeira and Walter's algorithm using appearance maps [2], we provide a brief overview of their algorithm in the next section.

2 The method of Bandeira and Walter

Bandeira and Walter's method [2] models an input image as the product of reflectance and shading, and assumes that only the reflectance changes due to weathering phenomena.

To decompose an input image into reflectance and shading, they use *Lab color space* that allows to handle luminance (L) and chroma (ab) separately. They assume that chroma values of shading are constant and chroma values of reflectance are given as ab channels of each pixel. On the other hand, luminance values of reflectance and shading are modeled as follows.

$$I_l(i,j) = W_l(i,j) \times S(i,j) \quad (1)$$

where i and j are horizontal and vertical coordinates of each pixel, I_l is luminance of the image, W_l is reflectance luminance represented as the weathering component, and S is shading luminance. The reflectance luminance W_l are computed based on a weathering degree map.

The weathering degree map is calculated with an appearance map that is constructed in advance based on the least weathered point and the most weathered point selected by the user. Weathering degree values are within the range of [0, 1] where 0 indicates the least weathered and 1 indicates the most weathered.

The reflectance luminance values are the average of luminance values of pixels whose weathering degrees are almost the same. The shading luminance values are calculated as $S(i,j) = I_l(i,j)/W_l(i,j)$. After the decomposition, the weathering degree map is updated, and then the deweathered or weathered reflectance is computed with the appearance map and the weathering degree map. Finally, a resulting image is obtained by combining reflectance with shading.

3 Modeling weathering effects with geometric details

We handle (de)-weathering effects where both shading and reflectance change simultaneously. Following the method of Bandeira and Walter [2], the region of interest (ROI) in the input image is decomposed into shading and reflectance based on a weathering degree map computed with the appearance map.

The left photograph in Fig. 2 exhibits a typical example where not only reflectance but also shading varies due to weathering. In this case, rusting causes fine-scale geometric variations on the iron surface. As illustrated in the right graph in Fig. 2, the variations are observed as a high-frequency pattern in the image, which is similar in other weathering examples such as peeling paint and moss as demonstrated in this paper.

Based on this observation and an assumption that the texture pattern on the object surface can be ignored, we consider the high-frequency components in shading as the geometric variations caused by weathering. As a preprocessing, we extract the high-frequency patterns and fill the ROI with the patterns using a texture synthesis method. Then, we add these synthesized patterns onto shading according to the updated weathering degrees. Reflectance is also calculated similarly to Bandeira and Walter's method [2]. Finally, we obtain resulting images by multiplying reflectance and shading. In the following sections, we describe each of these steps in detail. Although our approach cannot be applied to images with high-frequency texture patterns and/or many colors, it reproduces realistic results compared to previous approaches in many applications.

3.1 Extraction of shading details

Given a shading image S, we decompose S into coarse features and fine features using a multi-scale image decomposition presented by Subr et al. [12]. Because this decomposition can separate the fine texture from shading if the texture and shading are of different scales,

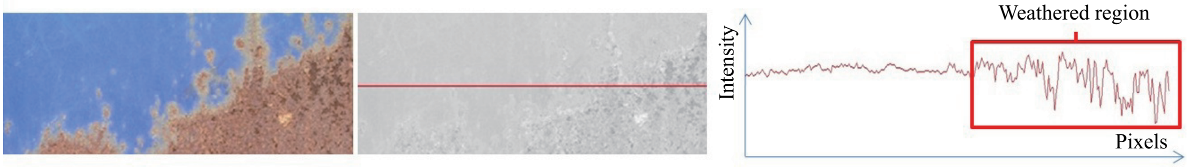

Fig. 2 A typical example of the fact that weathered regions often become rough. Left: A photograph of a rusting surface. Middle: shading of the left image. Right: intensity plots of shading along the red scanline.

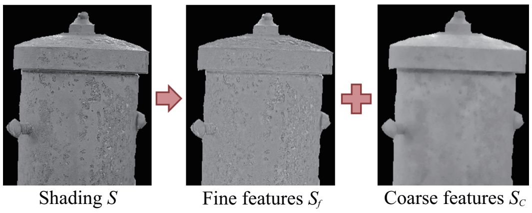

Fig. 3 Decomposition into coarse features and fine features.

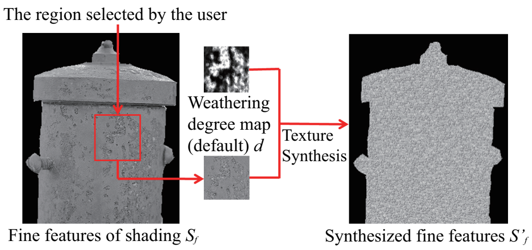

Fig. 4 An outline of the synthesis. Fine features of shading are synthesized in a weathered region based on a weathering degree map.

it works well for our purpose of extracting the high-frequency patterns. The shading image S is decomposed into coarse features S_c and fine features S_f as follows:

$$S(i,j) = S_c(i,j) + S_f(i,j) \tag{2}$$

The decomposed result is shown in Fig. 3.

3.2 Texture synthesis

To fill the ROI with extracted high-frequency patterns, we employ a texture synthesis algorithm by Ashikhmin [1]. This algorithm runs very fast and constructs results that often look good. Although it sometimes brings abrupt discontinuity depending on the input texture, it suffices for our purpose because the input texture in our case is just a rough pattern that does not require continuity.

The synthesis process is shown in Fig. 4. To ensure that the source texture pattern is obtained only from the weathered region, we calculate a binary mask M from the weathering distribution map d.

$$M(i,j) = \begin{cases} 1 \ (d(i,j) \geq t) \\ 0 \ (d(i,j) < t) \end{cases} \tag{3}$$

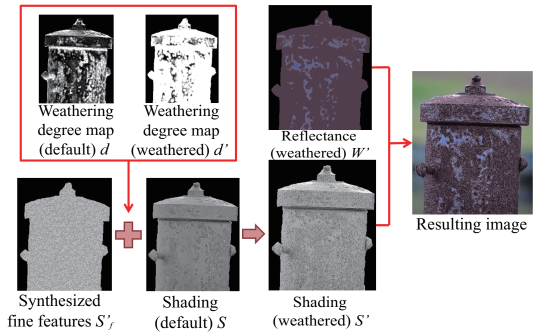

Fig. 5 An overview of synthesis of weathering effects with geometric variations. The weathered shading is calculated based on the weathering degree map and the synthesized fine features. The resultant image is obtained by multiplying the precomputed reflectance and synthesized shading.

where t denotes a weathering threshold. We found $t = 0.5$ works well for the results in this paper. The source texture pattern is sampled from regions where $M(i,j) = 1$ in order to obtain synthesized fine features S'_f.

Note that the texture synthesis may cause artifacts if the binary mask contains shadowed or non-weathered regions. This problem can be avoided by letting the user to manually specify a rectangular region in which the binary mask is constructed and the source texture is sampled. Fortunately, such additional user input is not required in most cases by setting the rectangular region around the most weathered point specified when constructing the appearance map.

3.3 Weathering with geometric details

After the preprocessing described above, the resultant shading is computed with the synthesized fine shading components S'_f, the initial shading S, the initial weathering degree map d and the updated weathering degree map d' as shown in Fig. 5. The fine components are added to the regions where weathering progresses to a certain extent:

$$S'(i,j) = \begin{cases} S(i,j) + S'_f(i,j) & (d'(i,j) - d(i,j) \geq t) \\ S(i,j) & (d'(i,j) - d(i,j) < t) \end{cases} \tag{4}$$

On the other hand, the reflectance variations are calculated using the appearance map according to the weathering degree for each pixel. Finally, a resultant image with detailed shading is obtained by multiplying the shading and reflectance values.

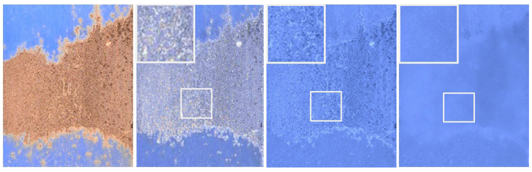

Fig. 6 A comparison of de-weathering processes. Left to right: the input image, a de-weathered result by Xue et al. [14], a de-weathered result by Bandeira and Walter [2] and a de-weathered result by our method. Magnified images are shown at upper left of the results. The original smooth surface is well reconstructed by our method while the geometric details due to rust remain in the results of the previous methods.

Fig. 7 Comparisons of mossy effects. Left: the input image. Middle: the resultant image by Bandeira and Walter [2]. Right: the resultant image by our method. Moss propagates with geometric details in our method while only the color changes in the previous method.

We also try de-weathering taking into account the geometric variations, i.e., recovery of the original surfaces of objects before going through weathering. This is a challenging task in general because the original surfaces are unknown. In contrast to weathering described above, we synthesize the high-frequency components of shading extracted from non-weathered regions. A comparison of de-weathering effects between the previous methods [14, 2] and our method is shown in Fig. 6. The original smooth surface is well reconstructed by our method while the geometric details due to rust remain in the results of the previous methods.

4 Results

Our implementation was written in C++, using OpenGL, GLUT and GLUI. We ran our program on a PC with an Intel Core i7 2.80 GHz CPU and an NVIDIA Quadro FX 580 GPU. The input images we used in Fig. 2 and Fig. 6 were directly taken from the paper of Xue et al. [14], and the others were downloaded from flickr (http://www.flickr.com/).

The sizes of the input images and the time for preprocessing (Sections 3.1 and 3.2) are within 265×333 pixels and 5 seconds. The time required to update a weathering degree map and to calculate reflectance and shading is almost the same as Bandeira and Walter's method [2] because the additional process is just to incorporate the high-frequency components that are synthesized in the preprocessing.

Fig. 1 and Fig. 7 show comparisons between our method and the previous method [2] to reproduce rusting and mossy effects. Note that in our results, the weathering effects with geometric details look more realistic compared to the results by the previous method.

5 Conclusion and future work

We have presented a technique for reproducing weathering effects taking into account the geometric details caused by weathering. Because we simply assume that geometric variations due to weathering appear as high-frequency patterns, we cannot handle intrinsic high-frequency texture patterns and low-frequency weathering effects. Nevertheless, we have demonstrated that our approach can achieve more realistic results compared to previous methods. For future work, we would like to develop a better deweathering technique that can restore the shapes of objects.

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